Crew and Space Transportation Systems Cost Model (CASTS)

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Abstract

As part of the MSFC Engineering Cost Office's new Program Cost Estimating Capability (PCEC) suite of cost estimating tools and capabilities, we are developing the Crew and Space Transportation Systems Cost Model (CASTS), a new, unique cost model for use in estimating crew and space transportation systems. This paper will provide an overview of the capabilities, estimating approach, historical database, and key features of CASTS as well as plans for future improvements.

Introduction

The Crew and Space Transportation Systems Cost Model (CASTS) is part of a new cost analysis capability intended for use in estimating space transportation systems including crewed systems and earth-to-orbit and in-space transportation systems. CASTS is currently being developed under a broader development effort led by NASA Marshall Space Flight Center's Engineering Cost Office (ECO) as part of the Program Cost Estimating Capability (PCEC). Under the guidance and direction of the MSFC ECO, PCEC is being developed by the Marshall Integrated Program Support Services (MIPSS) team led by Victory Solutions, Inc.

In keeping with the aim implicit in the last "C" in PCEC, CASTS is focused on developing an integrated capability coupling a parametric cost model with the historical data from whence it is developed, rather than "just" a parametric model. The great American historian and Librarian Emeritus of Congress, Dr. Daniel Boorstin, said "Attempting to plan for the future without a sense of history is like trying to plant cut flowers." In keeping with this maxim, CASTS reflects placement of a significantly greater emphasis on developing and documenting the historical database in a manner that provides the user/analyst with a level of transparency that allows insight and traceability of the database and analytical processes that are the basis for the model-produced estimate. The resulting capability is intended to provide the cost analyst with greater flexibility and access to a better understanding of the source data to aid in the process of developing the rationale for the basis of their estimates.

A primary staple of the NASA cost estimating tool suite over the past several decades has been the NASA Air Force Cost Model (NAFCOM). Since its inception in the early 1990's, by our estimation approximately 100 man years has been invested in developing, upgrading and updating, and maintaining NAFCOM. For the past twenty-five-plus years the two versions of NAFCOM, Government and Contractor, have provided a valuable tool that has served multiple generations of analysts well. After a thorough review by NASA, it was determined that the NAFCOM software as it stands today is not well-suited to adapt to the estimating needs of the NASA cost community. Among other issues, over time the depth of knowledge and understanding of the historical basis of NAFCOM's CERs necessary for developing traceable bases of estimates for NAFCOM-generated estimates has eroded. In response to these and other needs, the PCEC effort, including CASTS, was undertaken.

In addition to an increased emphasis on developing and understanding the historical database, the makeup of the CASTS historical database that provides the basis for the Cost Estimating Relationships (CERs) included in the CASTS model is comprised solely of historical data associated with crewed and space transportation systems. Historical source data involving spacecraft has been segregated and excluded from the CASTS data set. The spacecraft data set provides the basis for a separate cost estimating capability (model and database) included in PCEC for estimating the cost of robotic spacecraft.

CASTS Philosophical Approach

As a capability CASTS reflects a general movement in overall cost estimating philosophy from what over time has become a "model-centric" approach to a more "data-centric" approach. In summary, CASTS creates an environment that incorporates a change in focus from automation centric models to research centric data and, in the process, provides the analyst with a path to a more traceable, defendable, and thus credible cost estimate. In developing CASTS we have employed a working definition of a model as a set of mathematical relationships based on known historical data for use in estimating the cost of future systems. Our central focus is on the data and concomitant arithmetic, not the "bits and bytes" of the model.

This change in approach provides the analyst with both the challenge and opportunity to take greater ownership of their estimates by making the cost analysis a more important component of the resulting cost estimate. Using CASTS the cost analyst is provided with a capability that could be considered somewhat of a two-edged sword. The basis of estimate is no longer: "because the model said so", but rather something along the lines of: "based on the following historical data set, as modified by the following adjustments resulting from the following changes in context and assumptions between the historical data set and the system being estimated, the 'answer' is $X". Accordingly the analyst assumes a more direct responsibility for describing, defending, and thus "owning" the estimate. Some of the key differences in approach are highlighted in Figure 1.

Model Centric

- Focus is on how to use the model
- Model becomes a medium for communication with the technical community
- Model gets all the credit (or blame) for the estimate
- **Estimate becomes an evaluation of the present, rather than a prediction of the future**

Data Centric

- Focus is on the relationship of the data to the estimating problem
- Analyst must access and know the underlying data
- Puts onus for the quality of the estimate on the estimator
- **Done properly, can lead to value-added solutions**

Figure 1. Key differences in focus of model versus data-centric approaches.

As part of the PCEC development process CASTS incorporates the key components of the overall PCEC philosophical framework.

- Use the Best Data Possible

  The primary source for the CASTS historical database is the REDSTAR library. As described in more detail below, a central initial focus of the data gathering and analysis task was to review the NAFCOM CER data sets and research the REDSTAR library to first identify and review, then analyze and incorporate the historical data in the CASTS CERs. In addition, historical data for other space transportation systems was made available and was analyzed and adjusted for incorporation in the CASTS CERs. The result is a renewed documented understanding of a verified and validated data set available for review and analysis by the NASA cost analyst community.

- Total Transparency in the Analysis of the Data and the Development of the CERs

  As noted above, a key element of the CASTS philosophical framework is to ensure transparency between the CASTS model and source database such that the user/analyst has, as appropriate, access to the underlying source data that comprises the basis for the CASTS model CERs. The restricted and unrestricted versions of the CASTS User's Guides and Virtual Blackbooks described below are being developed in support of this objective.

- No Cherry Picking the Data Points

  In the course of reviewing and analyzing the space transportation systems historical data, all of the available data points have been considered and, absent a clear issue with the understanding of a data point itself, all points are considered in the development of the CASTS CERs either as part of the CER regression data set or included as an identified outlier data point with a calculated adjustment factor. No data points were excluded from consideration solely because they did not fit well with other data points in the CER data set. This has proven particularly difficult because there are relatively few space transportation system historical data points available and (as described in more detail below) there are typically several different, often countervailing, potential independent variables influencing the historical data points.

- Minimize or Eliminate Subjective Inputs

  Throughout the course of CASTS CER development, and in keeping with our overall data-centric philosophy, we have attempted to follow a data driven process for the derivation of subjective inputs. Our ultimately goal is to minimize CER inputs requiring subject analyst judgment to the maximum extent possible. In addition, we are striving to allow the user to follow the same process for determining input values across the different subsystems and independent variables.

- Emphasize Quality of Input Parameters over Quantity

  To the maximum extent possible the independent variables utilized on the CASTS CERs have been selected based on their predictive value while attempting to avoid "overfitting" as a means to obtain better fitting CERs. Meeting this objective has been particularly challenging for CASTS in some cases given the paucity of available data. Some of the subsystem CERs have minimal statistically significant predictive value in and of themselves, such that they are best used as source data points for analogous estimates rather than as CERs used to generate an estimate itself.

- Expect the User to Develop the Rationale for the Estimate
  As described above, ultimately the CASTS model and database are designed to provide the user with sufficient insight into the historical data and rationale behind the model to allow them to use the CASTS information as a starting point/basis for development of a traceable, defendable, and, thus more credible estimate.

CASTS in PCEC

As part of the overall PCEC architecture, CASTS fits as a set of tools designed specifically for estimating the cost of crewed and space transportation systems. In addition to CASTS, PCEC includes a Robotic Science Missions model and source database. As is the case with NAFCOM and many other cost models, due to the nature of the source information, including International Traffic in Arms Regulations (ITAR) and Export Control restrictions as well as the proprietary content of much of the data, access to the source databases is limited to those users with approved access to the REDSTAR database. As illustrated in Figure 2, the CASTS CERs and the unrestricted version of the CASTS User's Guide are available to all PCEC users, while the source databases, including the restricted version of the CASTS User's Guide and CASTS Virtual Blackbooks are accessible to NASA civil servants and support contractors with NASA User ID and account approval.

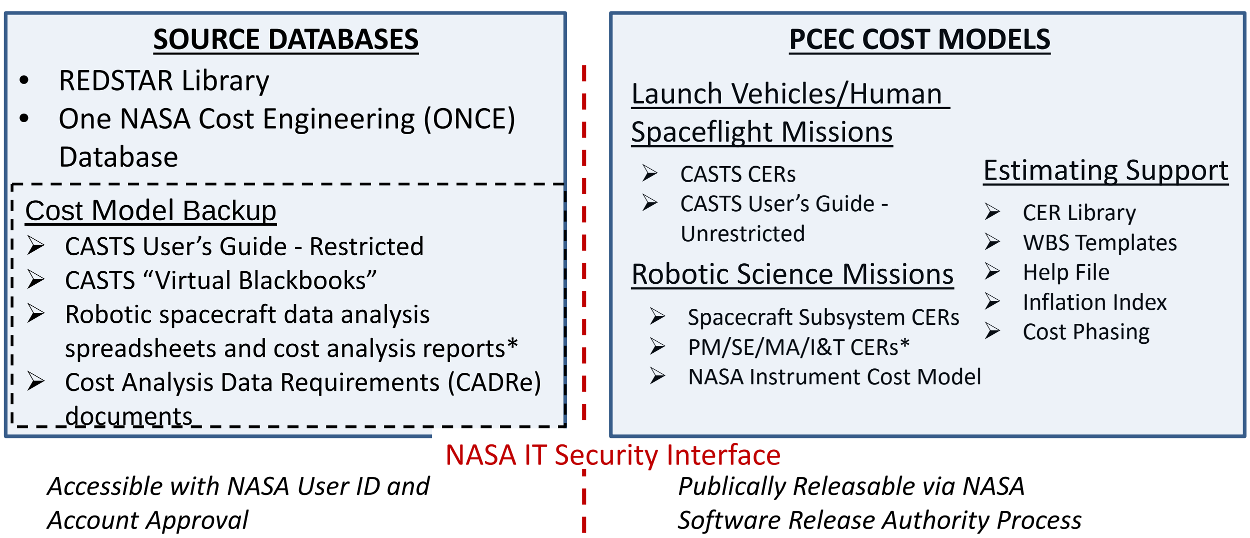


Figure 2. CASTS in the context of the overall PCEC architecture.

CASTS Development Process

The CASTS development process, summarized in Figure 3, has been and continues to be centered on identifying, reviewing, verifying, and then incorporating historical crew and space transportation system cost and technical data into the CASTS CER data sets. CASTS includes, but offers a more tailored estimating capability than NAFCOM. But without question the approximately one century of man year effort that has been invested in developing and supporting NAFCOM over the past twenty-five plus years is an invaluable asset that must not be dismissed. As such, the NAFCOM CER historical database provides the point-of-departure for developing the data sets used to generate the CASTS CERs.

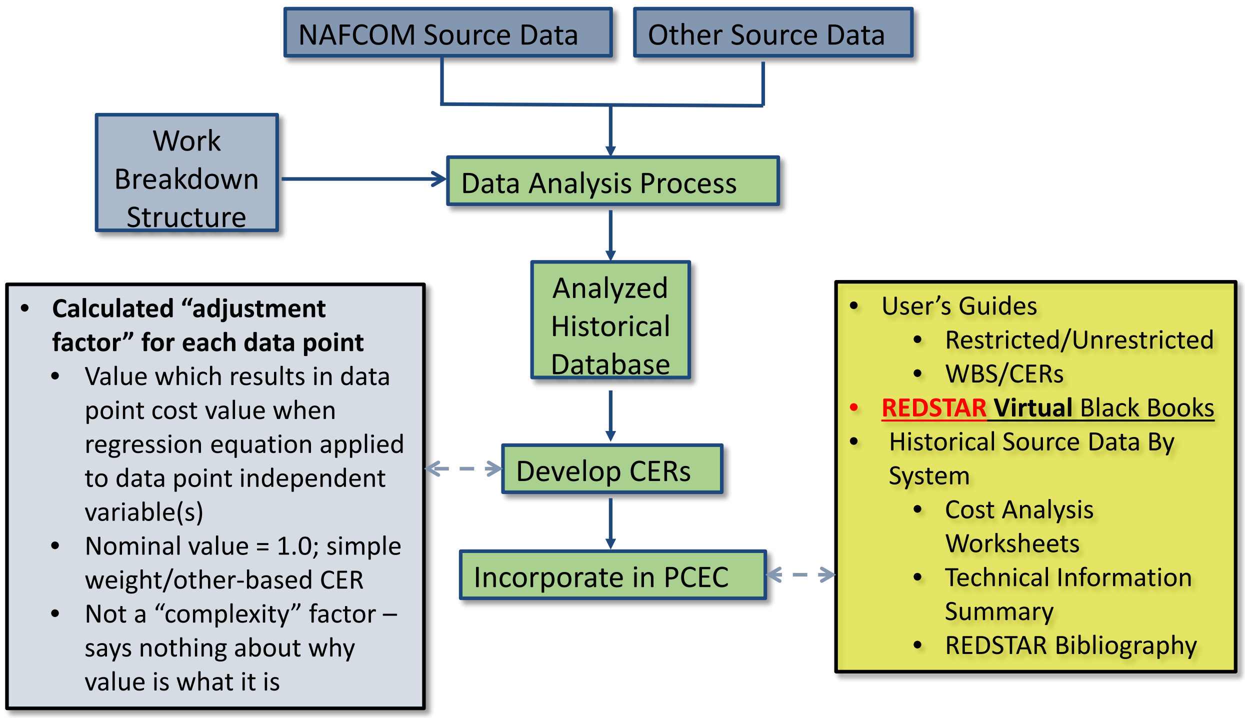


Figure 3. CASTS development process from source data to model and database.

The initial step in developing CASTS involved researching the REDSTAR database; identifying, reviewing, updating, and documenting the sources that provide the basis for the NAFCOM historical database. The primary task was to be sure we could identify and understand the source data and its transformation to implementation in the NAFCOM CERs. In addition, as applicable, the process involved segregating out spacecraft data points. Beginning from the data sets comprising the NAFCOM version 12 CERs, we worked backwards primarily utilizing common subsystem weight data for each historical system data point. We found that in many instances it was apparent that various releases of NAFCOM, sometimes tracing back over 20 years, had simply escalated the cost data from previous releases. With the invaluable help of MSFC ECO's Dr. Virginia Tickles and William (Billy) Carson, through this process we were able to identify the source documentation for most of the NAFCOM source data.

By its nature the historical data set for development and production of crew and space transportation systems is sparse. Development and production of such systems have been few and far between. Additionally many of the more recent new system development efforts have been undertaken in a competitive commercial environment such that much of the actual data is not available. As a result much of the database is composed of systems that by almost any standard can be considered "old". As a result, in many cases the database reflects development and productions processes and approaches that have been substantially changed and improved over time. For example, the use of Computer Aided Design (CAD) and engineering analysis computer tools such as NASTRAN have significantly changed the way engineering development is conducted since Saturn and even Shuttle systems were developed. However, given the scarcity of data, we utilized all available systems post-Gemini. In addition we identified, then sought and received permission, to add additional data points, particularly regarding Atlas and Centaur data.

One of the requirements for the development of PCEC is to conform the models, both CASTS and Robotic Spacecraft, to the NASA standard Work Breakdown Structure (WBS). That presents an immediate issue for CASTS because the NASA WBS levels for crew systems (WBS 5.0) and launch vehicles (WBS 8.0) do not provide the level of visibility necessary for estimating purposes. Accordingly, one of our initial tasks was to develop a WBS that encompassed all of the subsystems that might be included in a crew system or launch vehicle. The result was the CASTS WBS, shown in Figure 4.

Program Segment		
	Program Mgt & Support	
	Systems Engr & Integ	
Vehicle Segment		
	Integration, Ass'y, Checkout	
	Crew Structures	
		Wing
		Tail
		Fuselage/Body
		Capsule Structures
	Thrust Structure	
	Adapters	
	Secondary/Support Structs	
	Tanks	
	Intertank	

Vehicle Segment (cont'd)		
	Mechanisms	
		Thrust Vector/Flight Control
		Separation
		Recovery
		Other
	Main Propulsion Systems	
	Thermal Protection	
		Passive
		Re-Entry Leading Edges
		Re-Entry Heat Shield
	Propulsion	
		Liquid Engines
		Solid Motors
		Reaction Ctl/Orb Maneuv Sys

Vehicle Segment (cont'd)		
	Avionics & Power	
		Guidance, Nav, & Control
		Telemetry & Tracking
		Command, Ctl, Data Handling
		Range Safety/Flt Termination
	Electric Power	
	Shroud/Fairing	
	Crew Systems	
		Environ Ctl & Life Supt
		Displays/Controls
Software Segment		
	Flight Software	
	Ground Software	
Test Segment		
	System Test Operations	
	System Test Hardware	
Ground Segment		
		Ground/Test Support Equip
		Tooling

Figure 4. CASTS Work Breakdown Structure.

The WBS was developed with an eye toward expansion to ultimately allow for extension to incorporate all of the products and services that are included in producing and operating a transportation system such that development of a complete Life Cycle Cost (LCC) estimate will be possible within CASTS. So, for instance, the Ground Segment can be expanded to include launch and mission operations tasks such as vehicle processing, physical payload integration, flight-to-flight software design, crew simulation and training, and analytical payload integration analysis.

It should be noted that the WBS is intended to be sufficiently broad to account for any and all subsystems that might be included in a crew or launch vehicle system. It is not expected that any one system would include every subsystem in the WBS.

With the WBS developed, the historical source database, summarized in Figure 5, was identified and reviewed, and analyzed for assignment and incorporation in the CASTS CERs. With a few exceptions as appropriate, two CERs were developed for each subsystem, including Design and Development (D&D) and Flight Unit (FU). As we worked through the CER development process it became clear very early that the scarcity of data points coupled with the disparate nature of each system in terms of requirements and use posed a significant challenge in developing statistically meaningful CERs. Degrees of freedom quickly became a very valuable commodity.

Given the disparate nature of the small data set, there was substantial "clutter" within the data. The minimal number of data points combined with multiple potential independent variables to restrict the flexibility available to develop CERs. In addition, there was oftentimes a lack of and dissimilarity between sources in the definitions and "bookkeeping" of the cost of various subsystems.

Launch Vehicles	Liquid Engines	Software
Atlas V Common Core Booster	F1	SSME Adv Health Mgt Sys
Atlas V Centaur	J2	Orbiter Cockpit Avionics Upgrade
Apollo Command/Service Module	J2X	Orbiter Primary Avionics Software Sys
Apollo Lunar Module	RS27	Orbiter Backup Flight Software
Centaur D	RD180	BRAHMS
Centaur G' (Shuttle Centaur)	RL10	DART
Centaur G' CISS - ASE	RS68	X33
Shuttle External Tank	SSME	Centaur G'
Shuttle Orbiter	Solids	Atlas II
Shuttle Solid Rocket Motor	Titan IV SRMU	Atlas V
Shuttle Solid Rocket Booster	Athena Castor 120	
Saturn V 1st Stage (SIC)	Trident D5	
Saturn V 2nd Stage (SII)	Shuttle RSRM	
Saturn V 3rd Stage (SIVB)	Atlas IIAS Castor 4A	
Titan Centaur	Atlas V SRM	
Titan IV 5m Fairing	Ariane V EAP-P230	
Atlas I, II, IIA, IIAS	Pegasus	
Super Lightweight External Tank		

Figure 5. Systems currently included in CASTS historical source database.

Ever mindful of the elements of the PCEC/CASTS philosophy to emphasize quality rather than quantity of independent variables, minimize subjective inputs, and no cherry picking of data points, we worked to identify independent variables that would 1) provide reasonably good predictive value and 2) make sense from a causality perspective. What we found was invariably a combination of some or all of poor predictive values (i.e. P-values >> .05), counter intuitive results (i.e. cost increasing over time, cost decreasing with increased complexity), and conflicting and/or countervailing influences between potential variables (i.e. time vs. degree of new design vs. technology level vs. state of the art).

For example the launch vehicle propellant tank data set includes 13 data points taken from 9 systems. The list of potential independent variables includes type of fuel (LH2 versus RP), common bulkhead versus separate fuel and oxidizer tanks, year of development/first launch, level of system inheritance (i.e. Centaur G' (Shuttle Centaur) inheritance from Centaur D versus Saturn II lack of inheritance), materials (stainless steel versus aluminum versus aluminum lithium), construction method (pressure stabilized versus isogrid versus skin/stringer), overall system complexity and state of the art, and, of course mass (weight). Employing various variable combinations did not produce any usable set of independent variables. Among other issues, the P-values were generally poor and the exponent slopes were not always logical (e.g. cost increasing with complexity and time).

Our approach to addressing the situation was to work through each subsystem to develop a CER for each WBS element based on the best independent variable(s) we could identify given the source data set. We then calculated an "adjustment factor" for each data point in a CER data set. The adjustment factor is the value which, when multiplied by the intercept value of the CER, passes through the data point given the slope of the CER equation. The adjustment factor is not a "complexity" factor in that it says nothing about why the value is what it is. It is non-dimensional so that without access to the specific values of the objective independent variables of each system in the data set (e.g. weight), providing the adjustment factor values as part of the CASTS model and documentation does not violate ITAR, export control, or proprietary data restrictions. The adjustment factors are included as part of the unrestricted User's Guide available to all users. The cost and independent variable values and scatter plots are only available in the restricted Guide.

The preponderance of the resulting CASTS CERs ended up utilizing one independent variable – mass (dry weight). A few, avionics for instance, are multivariate. Some subsystems with few like data points, such as crew structures (including the Orbiter fuselage, wings, and tail and the Apollo lunar and command modules) were combined to create a single variable CER with each adjustment factor available as a basis for what really becomes an estimate by analogy. Cost-to-cost CER relationships were developed for WBS elements that have typically been estimated using "wrap" factors or similar. The independent variable is the sum of the cost of other WBS elements. For instance, the independent variable for the systems engineering CERs are the sum of the D&D (non recurring) and FU (recurring) costs. The CER is not simply a factor, but includes a slope and intercept calculated based on a regression of the systems engineering and D&D/FU cost of the systems in the historical database. Figure 6 provides the type of CER currently available for each WBS element.

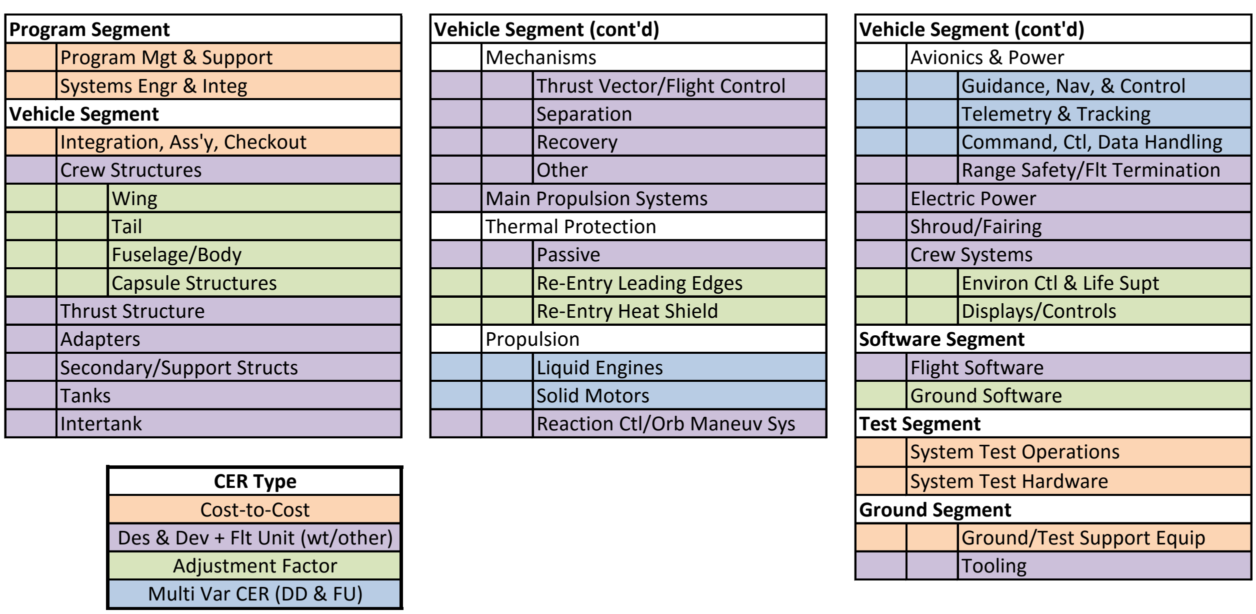


Figure 6. Current CASTS CERS for each WBS element.

It should be noted that in addition to the CASTS D&D and FU CERs, within each subsystem worksheet in the PCEC CASTS model, the ability to input learning and rate curve values to calculate fixed and variable production cost parameters and apply those to a production rate per year is available.

In stepping back and taking an overall hard look at the current set of CASTS CERs it must be said that they present somewhat of a mixed bag. Some of the CERs are not statistically significant, so that their use is really more as a data set that can be employed for analogy estimates. As discussed below, CASTS development continues. It is intended that the adjustment factor approach will eventually be superseded by a complexity generator that will provide greater insight into the cost estimate while meeting the overall goals of utilizing quality variables and minimizing subjective inputs.

For calibration and testing purposes CASTS was used to develop an estimate of the Space Launch System core stage then compared to a relatively detailed estimate developed using the PRICE model. Using the same input data set (e.g. mass statement, programmatics, etc.) the estimate was developed "blindly" without knowledge of the PRICE estimate results. We did not use any adjustment factors, leaving the value 1.0 for all subsystems. When results were compared the total CASTS estimate was less than 5% different than PRICE-based estimate. At a lower level of comparison there were some more significant differences, but at a top level the two estimates were essentially equal.

CASTS Database

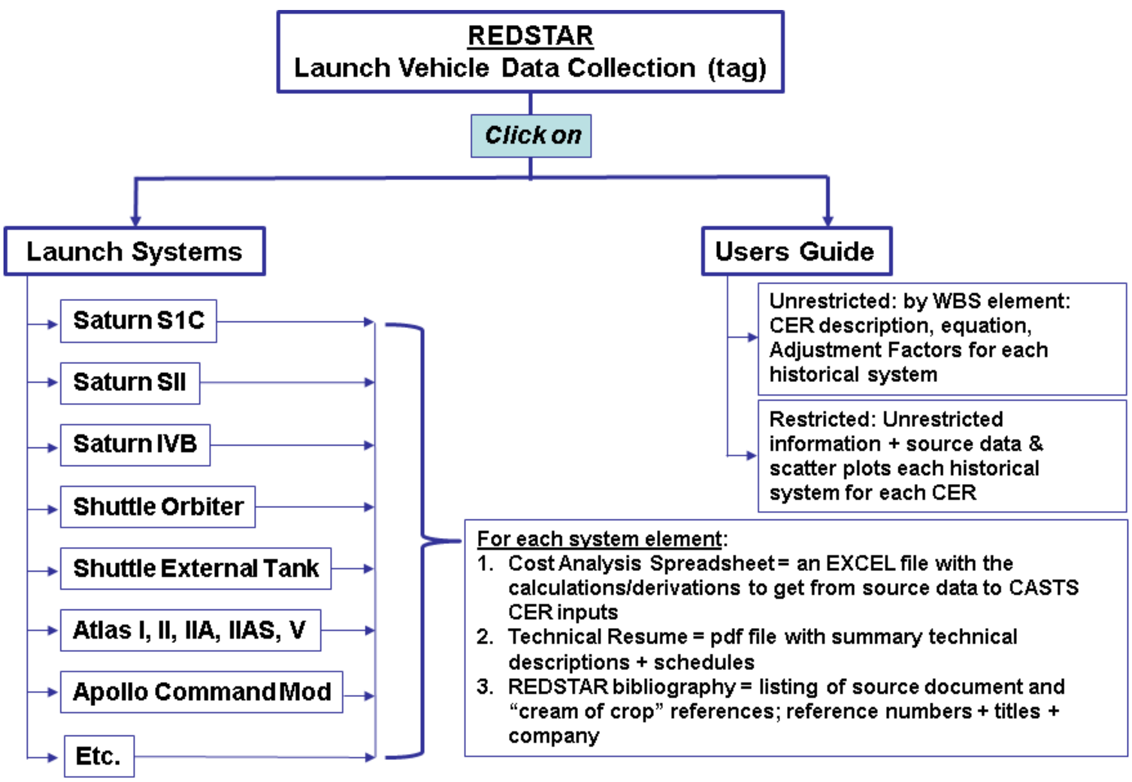


Figure 7. CASTS Launch Vehicle Data Collection in the REDSTAR library.

To meet the CASTS goals of traceability and transparency in the data and model, we are continuing to develop the Launch Vehicle Data Collection (Figure 7), composed of a set of documentation available to approved NASA users in the REDSTAR library and a subset of which is available to unrestricted PCEC users upon request. The documentation includes a User's Guide and, for NASA users, a set of Virtual Blackbooks (VBB). The VBB are being generated for each system in the historical database. Each VBB contains cost analysis spreadsheets tracing the source cost and technical data and analyses to the CER data inputs, a technical resume summarizing the technical and programmatic specifics of each system, and a source bibliography listing the "best" sources of information for each system contained in the REDSTAR library.

As we worked through the CASTS development process, and particularly as we began to exercise and test the model, it quickly became clear that some sort of guidance was required for a user to be able to navigate through the model. As a result we developed User Guides to make available to all users. As described above, of necessity due to ITAR, export control, and proprietary data, two versions were developed, an unrestricted and restricted version. The unrestricted version, an example of which is shown in Figure 8, includes, for each WBS element the CER equations and input parameters, a definition of the subsystems and description of any relevant information regarding the CER data set, and the D&D and FU adjustment factors for the data set. The Guide also includes general discussions regarding different model calculations (e.g. learning and rate curve [fixed/variable cost] calculations), and provides some user "tips" for navigating CASTS in PCEC. The restricted User's Guide includes everything in the unrestricted version plus the source data set itself (cost, mass, any other input parameters) and scatter plots of the CER and source data set.

CASTS User's Guide - Unrestricted
PCEC version 2.0.1 **January 2016**

WBS Element: Main Propulsion Systems

CER Equations: D&D $ = .7008 x Weight[illegible] x AF FU $ = .0102 x Weight[illegible] x AF

Inputs:

Dry weight (Weight), Adjustment Factor (AF)

Description:

This CER estimates the Design and Development and Flight Unit costs of the Main Propulsion System (MPS) of a launch vehicle element and includes (as applicable) feed lines, fill and drain, purge and vent, and pressurization subsystems. The Apollo CSM and LM data points were excluded from the CER calculation data set base due to the significant difference in requirements, design, complexity, and overall nature of those subsystems relative to the rest of the data set. As such the Apollo adjustment factors are essentially factors to adjust for analogous MPS systems comparable to the Apollo systems.

ent Factors:

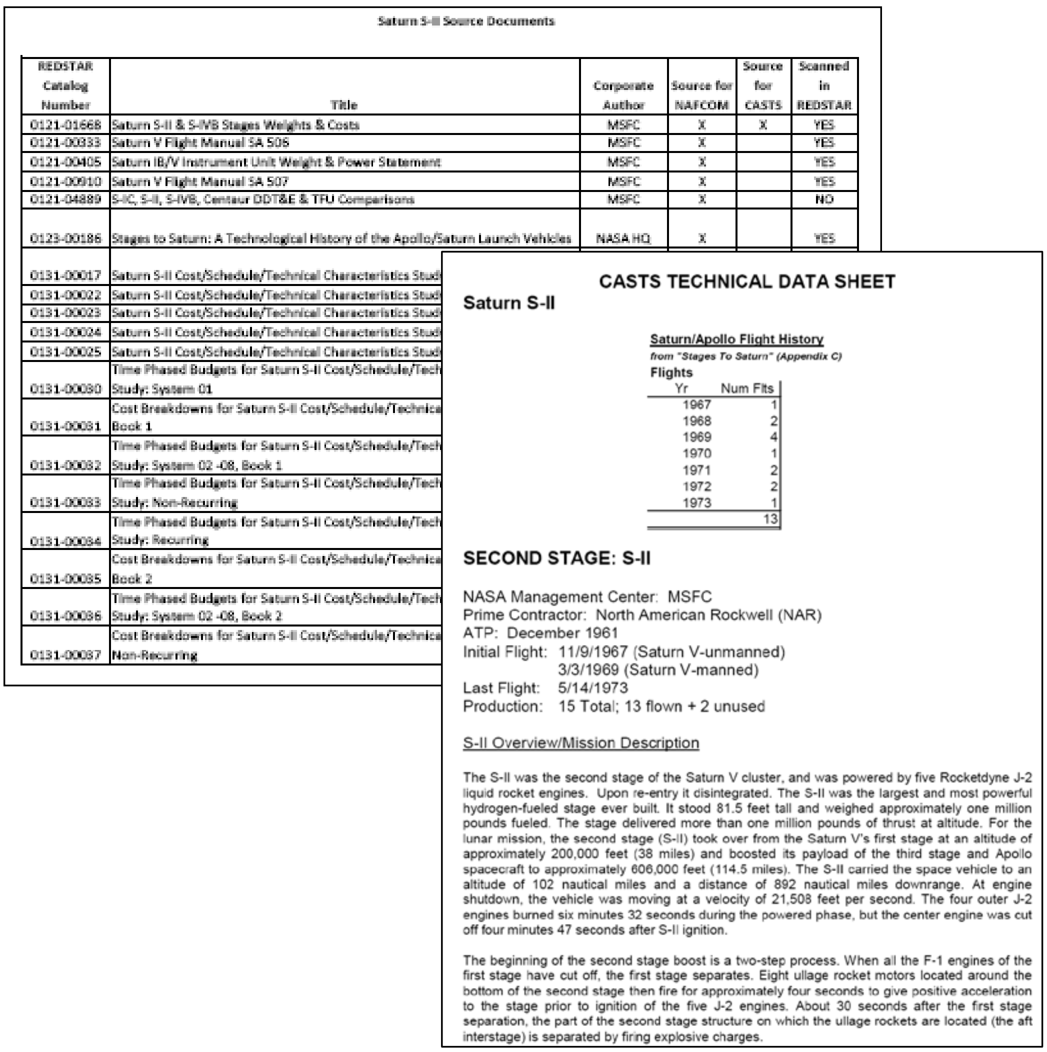
System	Description	DD	TFU
AV CCB	RP1	1.5620	0.3907
External Tank	LH2	0.7529	0.4280
SIC	RP1	0.7611	0.9420
Centaur D	LH2	2.2395	1.9872
Orbiter	LH2	1.1903	4.1059
AV Cent	LH2	2.7944	3.0632
SIVB	LH2	2.1854	0.5304
Titan Cent	LH2	0.4081	0.3005
Centaur G'	MPS-G' LH2	0.3331	1.9150
Centaur G' CISS	MPS-CISS LH2	0.4072	0.5143
SII	LH2	1.2450	1.5678
Apollo CSM	Main Propulsion	11.8526	11.6432
Apollo LM	Ascent	6.9662	10.6624
Apollo LM	Descent	5.9231	10.6106

Figure 8. CASTS Unrestricted User's Guide example – Main Propulsion Systems.

The Virtual Blackbooks, available to approved NASA users, will (when completed) be available through the on-line REDSTAR library. While the VBB's are not an official Cost Analysis Date Requirements (CADRe) document, they are patterned after the CADRe while taking a cue from the old NAFCOM paper-copy documentation that was contained, literally, in black binders in REDSTAR. A VBB will be generated for for each system in the CASTS historical database. Each VBB will contain a set of three files, a spreadsheet which starts with the historical cost and technical data as found in the source data, a pdf file summarizing key technical and programmatic characteristics of the system, and a pdf file listing the "best of" REDSTAR data sources by file number and name.

The spreadsheet will start from the source data, provided in tabular format, and include all calculations taking the source data to the input values incorporated in the CASTS CERs. The source data document numbers are included so that, should a user choose to do so, the input value in the CERs can be traced all the way back to the source data and the source data accessed and reviewed for any additional information and/or analyses the user may choose to perform.

The technical characteristics and REDSTAR source listing, an example of which utilizing Saturn SII data is illustrated in Figure 9, will provide the user with the capability to quickly review and assess the basis for any CER in the CASTS model. As a result, the user has the capability available to utilize the source data to adjust, modify, add additional data and/or completely redo or replace a CASTS CER. Additionally, the data can be accessed to develop a basis of estimate that includes a discussion/analysis/evaluation of historical data relative to the estimate being presented.



Saturn S-II Source Documents

REDSTAR Catalog Number	Title	Corporate Author	Source for NAFCOM	Source for CASTS	Scanned in REDSTAR
0121-01668	Saturn S-II & S-IVB Stages Weights & Costs	MSFC	X	X	YES
0121-00333	Saturn V Flight Manual SA 506	MSFC	X		YES
0121-00405	Saturn IB/V Instrument Unit Weight & Power Statement	MSFC	X		YES
0121-00910	Saturn V Flight Manual SA 507	MSFC	X		YES
0121-04889	S-IC, S-II, S-IVB, Centaur DDT&E & TFU Comparisons	MSFC	X		NO
0123-00186	Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles	NASA HQ	X		YES
0131-00017	Saturn S-II Cost/Schedule/Technical Characteristics Stud				
0131-00022	Saturn S-II Cost/Schedule/Technical Characteristics Stud				
0131-00023	Saturn S-II Cost/Schedule/Technical Characteristics Stud				
0131-00024	Saturn S-II Cost/Schedule/Technical Characteristics Stud				
0131-00025	Saturn S-II Cost/Schedule/Technical Characteristics Stud				
0131-00030	Time Phased Budgets for Saturn S-II Cost/Schedule/Tech Study: System 01				
0131-00031	Cost Breakdowns for Saturn S-II Cost/Schedule/Technica Book 1				
0131-00032	Time Phased Budgets for Saturn S-II Cost/Schedule/Tech Study: System 02 -08, Book 1				
0131-00033	Time Phased Budgets for Saturn S-II Cost/Schedule/Tech Study: Non-Recurring				
0131-00034	Time Phased Budgets for Saturn S-II Cost/Schedule/Tech Study: Recurring				
0131-00035	Cost Breakdowns for Saturn S-II Cost/Schedule/Technica Book 2				
0131-00036	Time Phased Budgets for Saturn S-II Cost/Schedule/Tech Study: System 02 -08, Book 2				
0131-00037	Cost Breakdowns for Saturn S-II Cost/Schedule/Technica Non-Recurring				

CASTS TECHNICAL DATA SHEET

Saturn S-II

Saturn/Apollo Flight History
from "Stages To Saturn" (Appendix C)
Flights

Yr	Num Flts
1967	1
1968	2
1969	4
1970	1
1971	2
1972	2
1973	1
	13

SECOND STAGE: S-II

NASA Management Center: MSFC
Prime Contractor: North American Rockwell (NAR)
ATP: December 1961
Initial Flight: 11/9/1967 (Saturn V-unmanned)
3/3/1969 (Saturn V-manned)
Last Flight: 5/14/1973
Production: 15 Total; 13 flown + 2 unused

S-II Overview/Mission Description

The S-II was the second stage of the Saturn V cluster, and was powered by five Rocketdyne J-2 liquid rocket engines. Upon re-entry it disintegrated. The S-II was the largest and most powerful hydrogen-fueled stage ever built. It stood 81.5 feet tall and weighed approximately one million pounds fueled. The stage delivered more than one million pounds of thrust at altitude. For the lunar mission, the second stage (S-II) took over from the Saturn V's first stage at an altitude of approximately 200,000 feet (38 miles) and boosted its payload of the third stage and Apollo spacecraft to approximately 606,000 feet (114.5 miles). The S-II carried the space vehicle to an altitude of 102 nautical miles and a distance of 892 nautical miles downrange. At engine shutdown, the vehicle was moving at a velocity of 21,508 feet per second. The four outer J-2 engines burned six minutes 32 seconds during the powered phase, but the center engine was cut off four minutes 47 seconds after S-II ignition.

The beginning of the second stage boost is a two-step process. When all the F-1 engines of the first stage have cut off, the first stage separates. Eight ullage rocket motors located around the bottom of the second stage then fire for approximately four seconds to give positive acceleration to the stage prior to ignition of the five J-2 engines. About 30 seconds after the first stage separation, the part of the second stage structure on which the ullage rockets are located (the aft interstage) is separated by firing explosive charges.

Figure 9. CASTS Virtual Blackbook example – Saturn SII.

Future Plans

As noted above CASTS is a work in progress. Among our higher priority future tasks, the most obvious is to continue to seek to expand the historical data base and incorporate additional data into the CASTS CERs. In the process, we will continue to seek to identify potentially meaningful independent variables with the goal being to replace the adjustment factors. In that regard we are investigating different approaches to development of objective complexity generators that will minimize subjective inputs while putting historical systems within the context of the complexity values.

A second priority is to expand the CASTS capability to allow development of a complete integrated Life Cycle Cost estimate. In order to accomplish that goal, we will add a time dimension and include additional WBS elements in the launch and flight/mission operations products and services areas, allow spreading of non recurring and recurring cost over time, and provide calculations of fixed and variable cost as a function of flight/production rate over time. The model will be fully integrated in such a way as to provide the output data that is incorporated in the common LCC "sand charts" showing LCC by phase by year for the entire life cycle of a system.

Another planned task is the incorporation of a Functional Breakdown Structure (FBS) estimating capability in CASTS. An FBS delineates cost by functions rather than a more typical end-item WBS. Examples of FBS elements include engineering, touch, manufacturing support, and quality assurance labor, and material and subcontract items such as valves, ducts, raw materials, etc.

Most WBS's utilized in parametric models are constructed on an end item basis (tanks, engines, avionics, etc.) because the typical non-cost independent variables (weight, thrust, lines of code) are much more straightforward and easily obtained. However, much of the historical data is in the FBS format and is not always accounted by end item. FBS capability will allow more visibility/flexibility regarding estimates for which end item WBS's are not as well suited.

For instance, many (some might argue most) proposed cost reduction/affordability approaches relate most directly to functions, not end items. Some examples: reducing touch labor through introduction of automated welding; reducing SR&QA labor by reducing the number of Government Mandated Inspection Points (GMIPS); and reducing facility O&M cost through sharing of facilities and support services. An estimate broken out by FBS elements could be utilized to estimate the cost savings resulting from these types of affordability initiatives.

As a second example, schedule tasks incorporated in, for instance, a master schedule usually address functions directly, not end items. The tasks to produce an end item like a propellant tank include "design", "analyze", "test", "fabricate", "inspect", etc. The FBS capability has promise for tackling the difficult task of integrating parametric-based estimates with schedules for incorporation in Joint Confidence Level (JCL) estimates.

As a simple example problem to which an FBS breakdown could be applied, assume an affordability initiative to introduce automated welding equipment to reduce the recurring cost of a propellant tank by reducing touch labor. The CER output for the tank flight unit is $10M. The manufacturing engineers estimate that introduction of the equipment will reduce touch labor by 60%. Upon review of the source data that provides the basis for the tank CER (in this case using example data taken from External Tank production), it is clear that the tank welding was performed manually for all data points in the source data set. In addition, review of the FBS data shows that touch labor is less than 15% of the total tank cost at a production rate of 4 per year. Accordingly, the CER is not adjusted for the new process at the gross CER output level of $10M. Instead, as illustrated in Figure 10, the 60% reduction factor is applied to the output of the FBS CER which provides the percentage of touch labor to total cost as a function of production rate.

The resulting estimate for touch labor before introduction of automated welding is $5.7M. When the 60% factor is applied, the savings is $3.4M, which equates to a reduction (at an assumed fully burdened rate of $150K per man year) of 22 heads of touch labor. Note how as production rate changes the relative percentage contribution of each FBS element changes. The labor elements percentages decrease as the rate increases while the material and subcontract percentages increase. This reflects the fixed nature of the cost of the labor relative to the more variable cost of the materials and subcontracted components.

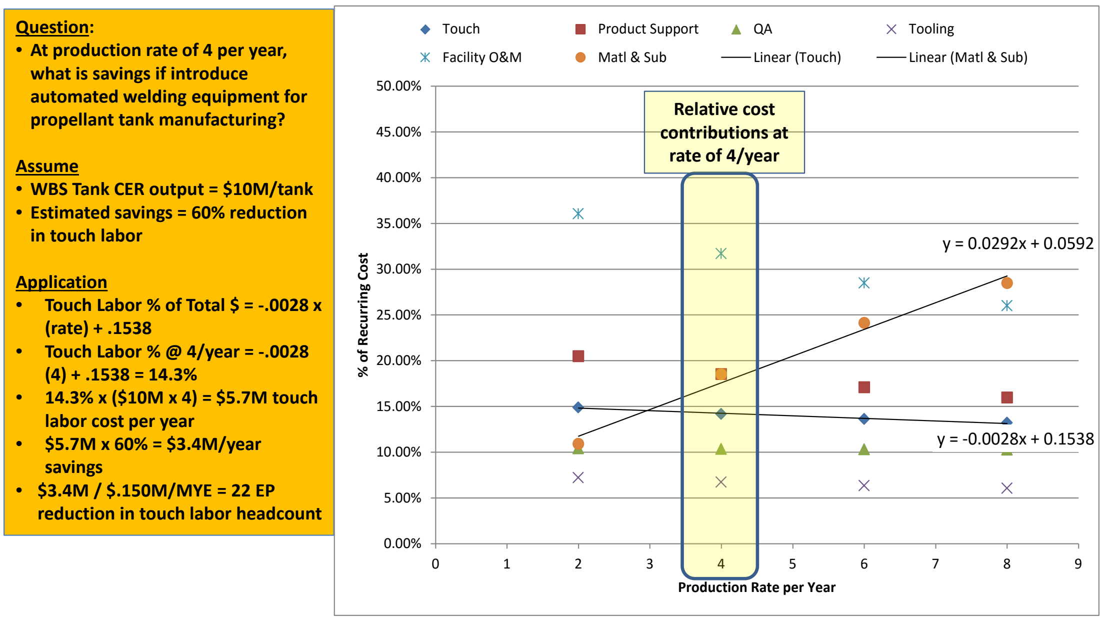


Figure 10. Functional Breakdown Structure analysis example.

Conclusion

CASTS is part of an overall effort within NASA to move from a model-centric to data-centric estimating approach. As such, CASTS is intended to be a complete integrated capability, including both a model and database. As CASTS development continues, our primary initial emphasis has and continues to be on database rather than model development. Ultimately our overall goal is to provide traceability and transparency of both model and data. At the same time as we continue development we are working to develop an estimating capability that provides both depth and breadth of both data and model. Taken together CASTS will provide analysts with tools to build traceable, defendable, and thus credible cost estimates.